FLEET ARC CENTRE OF EXCELLENCE IN FUTURE LOW-ENERGY ELECTRONICS TECHNOLOGIES

# Evaluation report: Home Schooled students. Two workshops – Quantum sparks and Energy.

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## Overview

A parent home schooling her 11-year old twin sons contacted FLEET via the Ask The Physicists Facebook page and asked FLEET if they could conduct some online physics-based workshops for her sons. Two workshops were organized: one on quantum electricity and a second on energy. FLEET arranged a third workshop to be conducted by OzGrav staff because of the twins' interest in space and black holes.

The workshops had an offline and online component. FLEET sent some pre-workshop hands-on activities for the twins to conduct offline. Their experience with the experiments and the results were discussed in the online component of the workshop. Some pre- and post-evaluation was done using Padlet, although this was informal and was used more as a reflective tool for the students rather than a formal assessment of learning.

## Workshop objectives

- To have students understand the basics of electricity, conductors, insulators and the structure of the atom
- To have students understand the concept of energy, the conservation and transfer of energy, and to understand the relationship between force, mass and acceleration.
- For students to be able to conceptualize how atoms, electricity and resistance work at the quantum level (qualitatively)
- To think critically about how we (society) use electrical energy
- An understanding of the features and functioning of circuits

## Highlights

- The twins could conceptualize electrons as waves – or having a wave-like function, and they could conceptualize how electricity and resistance works at the quantum level.
- The twins began to grasp the nature of superposition, or that electrons have an indeterminate position.
- The twins became aware of the issue of the increasing energy consumption of digital technologies and began to think critically about the impact of this issue and the potential solutions. They understood that developing materials with zero resistance could help make computation more sustainable.

The following sections outline the method used to conduct and evaluate the workshop, the outcomes from that evaluation and a discussion of what the outcomes mean relative to the workshop objectives.

## Method

The workshops were conducted for 11-year old twins being home schooled by their parents. FLEET developed and conducted two workshops for the students. The workshops had an offline and online component. The offline component involved the students setting up and conducting experiments, recording results and completing some pre-evaluation work to help gauge their understanding of the topic. Complete background and instructions were sent to the students to complete the offline component. Padlet was used to record their pre-evaluation work and it was where they could post the results of their experiments. There was some offline use of Padlet also where the students recorded their thoughts on the concepts of energy and quantum physics. The online component was a discussion of their experience with the experiment, their results and how they interpreted those results. This was linked to the theory that underpinned their experiments. The graphite circuits experiment was done online with the students and then discussed.

FLEET's research was linked to the experiments the students conducted and I facilitated a conversation on the problem of the increasing energy consumption of digital technologies.

The online components were conducted on Zoom and recorded.

### Evaluation

While formal evaluation of the learning objectives was not assessed via a pre- and post-evaluation method, analysis of discussion from the zoom recordings and what the students posted on the Padlet was used to give some insight into their learning.

The students were asked toward the end of each online component, what comes to mind when they think of energy, and quantum physics. They were asked to add these thoughts and any others to the Padlet document after the online session ended

### Interactive role playing

Both students started the workshops with a good understanding of structure of the atom. They were even aware of the electron cloud model of the atom and that electrons had a wave-like properties.

I discussed with the students the structure of the classical atom and its limitations. I then got them, along with their mother, to participate in some role playing to model the classical atom and then the quantum model of the atom – the electron cloud.

This was difficult given there were only three people to conduct the exercise. But, Mum played the role of the nucleus and the twins played the role of an electron around Mum. Initially as free electrons where electrons are perceived as particles buzzing around the nucleus, the student were also asked, to consider where the electrons were, which they could easily do because they could see the electron (themselves) and point to it as a definitive object in space and time. I then asked the students to join hands around their

Mum, the nucleus, and start the Mexican wave (as best as they could manage). They had to consider themselves as a single electron.

A short discussion was had about how in the quantum model of the atom, the electron's position can't be determined, but that using precise mathematics we can use probability to say it is more likely to be in one region around the nucleus than another. The idea in this scenario is that students can't point to an electron and say there it is as a definitive object in time and space. It is a single wave and could be anywhere around the nucleus.

A second role playing scenario was conducted to model resistance. Before this scenario occurred, the students were introduced to circuits and the role of electrons in the generation of current.

In the context of resistance, the students were reminded that electrons acted as waves and did not actually physically bounce off the atoms in the way a ball rebounds off a wall. Students were introduced to phonons and it was explained how it is the phonons that interact with the electrons as waves. The energy from the electron is transferred to the atomic lattice via its interaction with the phonons.

In the resistance scenario, one of the students played the role of an electron and the other student and mum played the role of atoms in the atomic lattice. The student playing the electron had about 6 pencils in his hand to represent the amount of energy the electron has - or the amount of force applied on the electron. I gave a signal that the battery was connected and then the student electron had to walk past his family of atoms, who continued to steal pencils.  The electron moves through the lattice a set number of times until they run out pencils (energy).

The students were asked what could they change to ensure the electron has sufficient energy to do the necessary work such as make their LED work. To examine their answers, the student electron was given about 10-12 pencil (greater energy or force). This represented a bigger battery. The exercise was repeated with the student electron making the same number of passes up and down his family lattice. He then compared the number of pencils (energy) in his hand.

In the final scenario the student electron is given just one pencil. This is to model a topological insulator, which the students were introduced to in the chat about circuits and the introduction to FLEET research. This time the student travels down one side of the atomic lattice and does not interact with the atoms/phonons. The electron moves through the lattice without any energy loss and therefore has energy to do the necessary work. The students were asked about the amount of energy that would be required to enable that electron to flow through the circuit and for example make a light glow and what the implications might be for the energy consumption of digital technologies.

## Graphite circuits

Students did the simplified version of the graphite circuits activity from FLEET Schools. Students constructed the graphite circuits and determined how long they could make the circuits before the LED would not work. Students were asked to consider what was happening to the LED the further it got from the battery and why it stopped working at a certain distance from the battery.

## Energy experiments

**What is energy and the two main forms: Kinetic and potential energy**
Activity. Double ball bounce (Best done outside)
Use a basketball and a tennis ball to examine potential/kinetic energy and transfer of energy

**Materials:**

- basketball
- tennis ball
- Optional (a third ball, that is smaller than the tennis ball, eg squash, ping pong or golf ball)
- Optional – raw eggs, water balloons

**Method**
Check out the FLEET home science video for a demo - https://www.fleet.org.au/blog/double-bounce/

You could just drop the balls one at a time then one on top of the other and observe, but let's add a bit of scientific rigour to this activity to help us understand what is happening.

1. Use a metre ruler /tape measure and drop the basketball from the one metre mark. Record the height it reaches on the rebound off the ground.
2. Repeat this with a tennis ball.
3. Hold the tennis ball on top of the basketball and drop them together from the 1 metre mark. How high does the tennis ball go? How high goes the basketball go?
4. If you feel game, try this with the third ball. How high does the third ball go? [Yes, it can be tricky to balance all three balls on top of each other – keep trying.]

**Things to think about**
What happened to the basketball when you dropped it with the tennis ball on top?
What did the tennis ball do when it was dropped with the basketball?
Can you explain why?

**Two ideas to examine the effect of mass and velocity on kinetic energy**

1. Materials: Two toy cars and a board that can be used as a ramp (could be stiff cardboard from an old box
   Place one car about 1-2 cm away from the foot of the ramp – facing forwards. Set an angle for the ramp. Place the second car half way up the ramp and lined up so that it will hit the rear of car at the foot of the ramp. If you have lined up the cars correctly car one should hit the rear of car two and cause car two to be bumped forward a certain distance. Measure the distance car two moved. Repeat this three times. Calculate the average distance car two moved. Now place car one at the top of the ramp. This will give it more speed (velocity). Measure the distance car two moves this time after it has been hit by car one. Now add some weight to car one – eg blutack some 50 cent coins to it. What effect does adding weight (mass) to car one have on car two when struck?

2. Set up a pendulum eg a piece of dowel with a string tied to it. Find something that will act as a small bag that you can put in different weighted objects, for instance a table tennis ball, lead sinker, etc. Fix the bag to the bottom of the string acting as the pendulum.
   Position an egg in the firing line of the weighted bag at the bottom of the pendulum and experiment with the different effects of mass and velocity. Eg the further you pull back the weighted bag on the pendulum the greater its velocity. The heavier the item in the bag at the bottom, the greater its mass. Note, this might get messy so a container under the egg might be useful. The mess free version is to have a block of wood standing up in the firing line and see what will knock it over and how far it gets propelled from the force of the pendulum.

Questions to ask yourself. What effect does mass and velocity have on kinetic energy? Remember the more energy something has, the more work it can do. The work that we are interested in is the distance car two will move, or hitting the egg (trying to crack it).
Why do we repeat each test 3 times?
Do you think if you set up separate ramps and cars you would both get the exact same measurement for each test?

## Results

This section outlines the outcomes from the two workshops. As noted, there was no formal evaluation of learning, but some insight can be gained from analyzing the pre- and post-contributions to Padlet and the dialogue that occurred in the online component of the workshops.

In an initial zoom meeting to establish student interests and to gauge their level of understanding, it was clear that, for 11-year old students, they had a high level of understanding of the scientific theory relevant to the workshops. They could describe the classical and quantum atomic structure and that electrons were waves, though they struggled to conceptualize how electrons as waves behaved. See Figures 1(a)(b) below. Note, they mentioned in their pre-evaluation Padlet document that they have chickens called Proton, Neutron and Electron suggesting they have a high awareness and interest in the subject matter. Without being aware of the actual equation, the students, could articulate at a basic qualitative level the relationship between force, mass and acceleration. They described electricity as energy that flowed through a circuit and they had some understanding that it is the electrons that flow.

The transcripts of the dialogue, and their pre- and post-work were analyzed for broad themes.

The results from the Graphite circuit workshop are presented first, followed by the results of the second workshop, Energy.

## Pre-evaluation

### Draw an atom.

I asked the students to draw an atom before they read any notes, conducted experiments or had the online component with me. Both students drew an atom with a distinct nucleus and electrons based on the electron cloud model. See Figures 1(a)(b) below. This apparent understanding aligns with the initial conversation I had with them to determine their level of understanding.


Figure 1(a) Student pre-evaluation drawing of an atom. Note their description of an electron cloud. Protons and neutron in a distinct nucleus are also apparent.


Figure 1(b) Pre-evaluation drawing from the second student (brother). Again, electrons are drawn in a cloud surrounding the nucleus as are the distinct nucleus with protons and neutrons.

## Pre- and post-evaluation questions

Table 1 outlines the pre- and post-evaluation comments for the students' perceptions of quantum physics and electricity. The students' responses were combined because both had the same pre- and post-thoughts for both questions. The exception was one student included quantum tunnelling in the post-quantum response. A pre-evaluation only was conducted for the questions, What comes to mind when you think of electricity, because a lot of their post-understanding became apparent in the conversation during the online component. The comparison of pre-and post-electricity is examined in the online component.

In their responses to the quantum question there is a shift away from space and size (that it is about really small stuff) to more sophisticated concepts of what is happening or can happen at the quantum level, for example, superconductors, and quantum tunnelling. They also now include resistance and circuits in the context of quantum physics.

Table 1. From workshop 1. Graphite circuits. Responses to the questions, What comes to mind when you think of electricity, quantum?

| **Pre-quantum** | **Post-quantum** |
|---|---|
| Wormholes, black holes<br>Tiny, molecular, too small to see, atomic<br>Quantum computers | Superconductors, atoms splitting, electron waves, circuits, resistance, quantum tunnelling |
| **Pre-electricity** | |
| electrical power, cables, lights, energy, power, electric, flow of energy | See online component |

## Online

### Graphite circuits

The results relevant to the online component come under the following broad topics that formed the online discussion:

- Tell me about atoms
- What is electricity
- Building circuits and resistance

Tell me about atoms

As noted, both students had a good understanding of the structure of an atom and they understood that electrons existed as waves in a cloud around the nucleus.

One student described his drawing of the atom as follows:

> *If you zoom in you will see little red and blue balls. They are the protons and neutrons in the nucleus. Then you have your electron cloud. Some people talk about strict orbits, some draw clouds. In that drawing I draw electrons as a cloud, but sometimes I might draw orbits*

They did struggle to articulate how an electron as a wave worked or existed.

> *I am not sure. I want to say that they are a cloud around the nucleus and they just zip about, but then I think I am not quite sure. I am unsure if there are orbits within the cloud*

As the online discussion progressed and they participated in the role playing to understand the electron cloud model, the students developed a deeper understanding of electrons as waves and their role in generating a current.

For example, following examination of an image of the orbital model of the atom where students could definitively point out the position of the electron, I got them to role play the electron cloud model where they joined hands around the nucleus. I asked students where that electron was now. They asked whether, “it was all of it?” That is, the students were unable to pinpoint the position of the electron, but questioned if the electron was all around the nucleus at the same time, which is not technically correct, but it suggests the students were starting to develop some understanding of superposition.

This understanding developed further during the discussion about electricity, construction of the graphite circuit and role play about resistance.

What is electricity

When the students were asked to describe how electricity works, one of the students replied, "it seems to flow". They could also state that it was the electrons that flowed in the circuit, but this somehow conflicted with their understanding that electrons were waves.

The students were thinking critically about electrons as waves and questioned, how the electrons as waves generate electricity.

> *"…the electrons. I had an idea. What if the electrons aren't flowing and…it is a wave going through it."*

Both students could describe a conductor and insulator

> *"…but a conductor makes it easier for electricity to flow through it. In an insulator it is hard for the electricity to flow through it."*

There real learning came in their exposure to the concept of resistance

### Building circuits and resistance

The students noticed that their LEDs got dimmer the further they got from the battery and surmised that this was because "energy got lost on the way." They also thought that the heat was lost through friction somehow as the electrons moved through the circuit.

The final activity was the resistance role play. Combined with their graphite circuit activity the students had the following comments about what they learned:

> *"Graphite is a conductor, but not too good"*
>
> *"[re: resistance] I understand that force – that you need to apply more force to make sure that it will reach the destination"*
>
> *"If I [as an atom in the lattice absorb energy from the electron] I will start to jiggle and come apart perhaps. And I feel heat"*
>
> *Re: resistance "Electrons lose energy"*
>
> *[The ideal circuit] "would have no resistance."*

Their responses suggest that they have a deeper understanding of resistance and the role of resistance in energy loss to the system. They understand now that circuits that have zero or low resistance require less force to achieve the same amount of work. That is they are more energy efficient.

## Energy

In the pre- and post-evaluation responses, here too, only pre-evaluation responses were collected to the question, What comes to mind when you think of energy, because the online component revealed a lot of their post-evaluation understanding. See Table 2. The students' pre-evaluation responses are single words related largely to types of energy. The exception is pone students' drawing of the electrical cable with electrical energy. Unfortunately, we neglected to discuss with the student what was happening in this drawing. In the post-evaluation responses noted in the online component there is a shift to how we use energy (increases the force you need to move an object) and what uses energy (digital devices). The post-energy conceptions were taken from the online transcript. See Appendix 1.

Table 2. Pre-energy conceptions from Padlet. The post-energy conceptions were extracted from the online component of the workshop

| Pre-energy conceptions | Post-energy conceptions |
|---|---|
| Heat, light, electricity, friction, forces<br>Electrical energy – see image below | See online component |

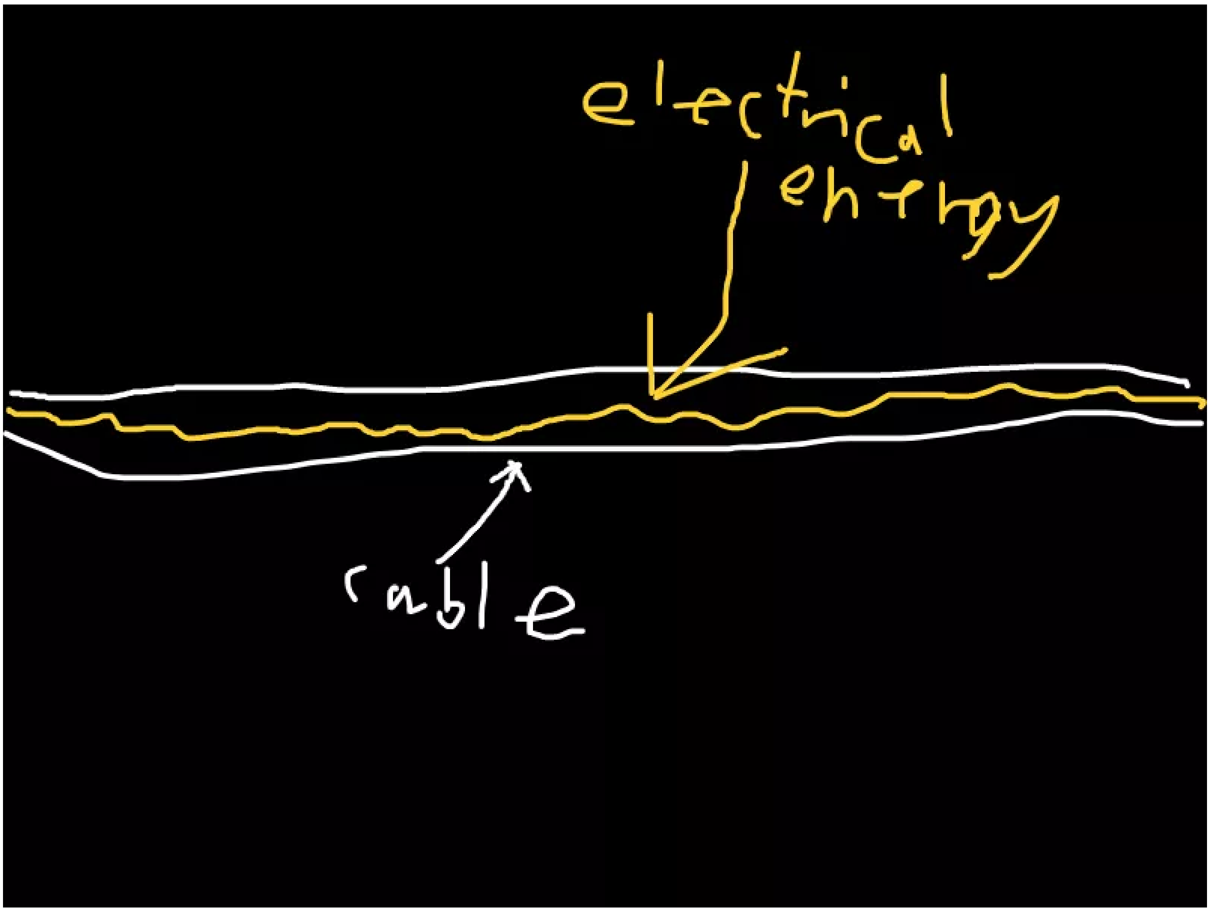


Figure 2. Pre-evaluation conception of energy

**Online component**

The online component centred around the outcomes of their pre-online experiments: the crashing cars and pendulum with most of the discussion on the latter experiment. There was some return to the previous workshop with further discussion on circuits and quantum.

It proved difficult to differentiate between what the students already knew about the relationship of force, mass and acceleration but simply found a new way to observe it through the two experiment activities, and what was actually something new that they had learned from the experience. But following the experiments, the students did show they had a good grasp of the relationship between force, mass and acceleration. They also showed they were thinking critically about the unsustainable energy consumption of digital devices.

Force, mass, acceleration
The students understood that the more friction there is, the greater the force needed to overcome it and that friction creates heat. They could link this to the heat generated by digital technologies, though they needed prompting to connect it to the need to develop more energy-efficient devices.

> *[In the pendulum experiment what were you changing each time to affect the outcome?] "The first time with bean bags we changed the mass and then we changed the angle to 90 degrees we changed the acceleration."*
>
> *"We make stuff more energy efficient. We can keep experimenting with graphene to make it stronger (I mentioned it was brittle)…We can experiment with other conductors that are as powerful as graphene, but where quantum tunneling does not happen."*

## Discussion

Relevant to the workshop objectives, the broad outcomes from these workshops are the following:

At a qualitative level, while the students already had a basic conceptualization of the atom at the classical and quantum level; they can, following these workshops, now also conceptualize how electricity and resistance works at the quantum level. They were exposed to the concept of superposition and appear to be at least thinking critically about it.

Students successfully constructed a graphite circuit and they appeared to understand the components required to make a circuit work and could describe what a conductor and insulator is. They could articulate that it was resistance (electrons losing all their energy) that meant the LED got dimmer the further it got from the battery.

The students began to think critically about the increasing energy consumption of digital technologies, and they understood that it would be more sustainable to have materials that could enable electrons to flow without energy loss.

### Limitations

As noted, the students had an advanced understanding of the concepts presented in the two workshops. And because the students did the experiments at home, it was sometimes difficult to work out what was students repeating what they already knew and what was for them a novel understanding. This reflects the informal method used that was not designed to capture learning outcomes with any rigour.

### FLEET reflection

The value of the post-evaluation question, what comes to mind when you think of quantum physics is questionable. Although for academic rigour it might be argued that the same question must be asked, students struggled to link what they had learned to quantum physics. A small proportion of students began to conceptualize quantum physics with descriptions such as it being the energy and matter in the world; that it was the behaviour and nature of the atom, or that electrons were waves, but most fell back to similar descriptions for electricity.

A more effective way to approach this question might be to simply ask what comes to mind when they think of electricity, atoms and resistance. One could then examine how much of their description reflects an understanding of quantum physics. This will need to be tested.

There is also scope to use online platforms more effectively to more formally evaluate learning and critical thinking.

# Appendix 1

Transcripts for the online components of the two workshops

Graphite circuit workshop

| Transcript | Analysis |
|---|---|
| They have chickens called proton, neutron and electron | |
| Tell me about your drawings of atoms. What do they mean to you? | |
| S1. If you zoom in you will see little red and blue balls. They are the protons and neutrons in the nucleus. Then you have your electron cloud. Some people talk about strict orbits, some draw clouds. In that drawing I draw electrons as a cloud, but sometimes I might draw orbits | Describing the quantum model of the atom<br>Being aware of the different models – orbital and quantum (electron cloud)<br><br>**[Aware of the electron cloud model of atom]** |
| S2. My electrons are an electron cloud. | Being able to draw the quantum model of the atom |
| ME: Describe what you think an electron cloud is? | |
| S1. I am not sure. I want to say that they are a cloud around the nucleus and they just zip about, but then I think I am not quite sure. I am unsure if there are orbits within the cloud | Struggling to describe / understand the nature of electrons in the electron cloud<br><br>Wondering if the electrons are orbiting within the cloud |
| S2: I am unsure | Being unsure about the nature of the electron cloud [trying to conceptualize the electron in electron cloud model] |
| ME: What you are talking about is electrons at the quantum scale.<br>Showed image of classic atom with electrons as particles in orbit about nucleus. Demonstrated that in this image one can argue point to the electron particle and say that is where the electron is | |
| Demo – S1/2 around their Mum and did the Mexican wave. I asked, can you say where the electron is now | |
| S1/2: Is it all of it | |

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| ME: Explanation of electrons as waves and their position is based on probability.<br><br>ME: Describe to me how electricity works<br><br>S1 – it seems to flow<br><br>ME: What flows<br><br>S1 – the electrons. I had an idea. What if the electrons aren't flowing and…it is a wave going through it | Describing the nature of electrons as waves. Developing understanding of superposition - maybe<br><br>Describing electricity as something that flows<br>Understanding that it is the electrons that flow. Raising the question that electrons might not flow but are a wave going through the circuit. |
| ME: The electrons are waves and the kinetic energy is propagating forward in a wave.<br>As you pointed out, the electrical energy used to make the light work – or do work – is not the kinetic energy of the electrons. Not stuff we need to know about for today<br>The way we get the electrons to flow is add a force<br>We use copper in our wires to conduct charged particles because copper is a good conductor. Do you understand the difference between a conductor and insulator?<br><br>S1 – yes<br><br>ME: What makes a good conductor?<br><br>S1: Not exactly sure but a conductor makes it easier for electricity to flow through it. In an insulator it is hard for the electricity to flow through it. Sometimes it even can't penetrate.<br><br>ME: I explain the difference between conductors and insulators – what makes a good conductor. How attaching a force (battery) to circuit enables electrons to flow. I ask what happens when you get a two negatively charged particles together – | Understanding that conductors enable electricity to conduct more easily<br>Understanding that insulators are materials that electricity can't flow through easily.<br>Understanding that some insulators don't let any electricity (current) through. |

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| eg electrons in copper circuit and electrons from a battery? | |
| S1: They push away from each other | Understanding that like charges repel and that opposite charges attract each other. |
| ME: Yes, what about negative and positive charge? | |
| S1/2 – attract | |
| ME: Showing image of circuit – as soon as you get electrons flowing, you get what? | |
| S1: You get a circuit | Understanding that when you get the electrons flowing in a circuit you have a working circuit |
| ME: Yes you have a circuit, but when you have electron flowing you have current and the generation of electrical energy.<br>With current you get the generation of a magnetic field and then the flow of electrical energy (I say here that the electrical energy occurs on the outside of the wire – which might not be technically correct – this needs some thought) | |
| ME: show me your set up for set up for the graphite circuit<br>Demo of graphite circuit<br>Make the LED work – then make your circuits as long as possible and still have your LED work. Observe what is happening to the LED the further it gets from the battery? | |
| What happens to your LED when you place it and the battery on just the paper | |
| S1/2 – it doesn't work | Observing that the LEDs don't work when just on the paper with the battery |
| ME. Why not | |
| S1 – Not sure – maybe paper is not conductive? | Showing good intuition that the paper is an insulator (or doesn't conduct) |

| | |
|---|---|
| ME – yes paper is an insulator. Paper is made from wood and wood is a good insulator | Observing that the LED gets dimmer the further it gets from the battery. |
| (S1/2 have made longer circuits – S1/2 notices the led gets dimmer the further it gets from the battery | |
| ME: why is it getting dimmer? | Perceiving that the light gets dimmer because energy is being lost between the battery and the LED |
| S1 – some energy is getting lost along the way perhaps | |
| ME: correct<br>How is that energy being lost? | Perceiving (correctly) that the energy is being lost as heat |
| S1 – maybe as heat energy | |
| ME: It is, but in too small amounts for you to be able to detect in such a small circuit. But you will notice it in your laptop or phone | Noticing that their laptops are getting hot and that is wasted energy |
| (S1/2 feel their laptops and notice they are hot) | |
| ME – so where is the heat coming from – how are we losing energy? | Thinking that the heat is coming from friction as the electrons move through spaces in the circuit |
| S1– maybe from the friction of them moving through the space…but then…. | |
| ME – what is moving through the space? | |
| S1 – maybe as they are moving there is some sort of friction | |
| ME: What is moving? | |
| S1 – the electrons | |
| ME: correct – it is the electrons that are losing energy. But it is not really friction. I explain that when electrons were considered particles that that was considered what was happening as the | |

| | |
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| electrons bounced off or interacted with the atoms<br>Trying to show how to measure resistance with multimeter<br><br>Sharing image so ppt – image of resistance – resistance slides<br>The battery is the force you apply to the electrons. Devices will need a specific amount of energy to do the necessary work. | |
| I describe that atoms in a lattice are always moving a little bit. I note that to stop atoms moving you need to cool them down to -273 degrees (or zero kelvin)<br><br>S1 But that is only theoretical as the only thing that can theoretically reach that (temp) is a perfect crystal and so far we have found none of those<br><br>ME – correct.<br><br>Demonstration of resistance dance and explanation of resistance (phonons – electron interaction) | Understanding that atoms (or anything) can only theoretically reach zero Kelvin.<br>Knowing that we have not found a material that can reach zero Kelvin (I am unsure if it is actually the material or our technical ability or actual ability based on laws of physics that says we can't reach zero Kelvin) |
| What could we change to our graphite circuit to make the LED work at the distance it is from the battery where it no longer works?<br><br>S1 – the charge of the battery perhaps<br><br>ME – yes a bigger battery – what else<br><br>S1 – make a short cut<br>Or make it more conductive<br><br>ME – yes – get a better conductor. Better than graphite<br>What if we could make a conductor that doesn't lose any energy– we give the electron 10 pencils of energy and as it propagates through the circuits it doesn't | Understanding that increasing the force (bigger battery) will increase the electrical energy available to do work.<br><br>Understanding that improving the conductivity of the circuit will enable more electrical energy to be available to do work |

| | |
|---|---|
| lose any energy (pencils). What would be the implications of that?<br><br>S1 – implications?<br><br>ME: What would it mean – at the moment even the best conductors such as gold, still have resistance. They still lose energy via resistance. What if we could invent a conductor that had no resistance<br><br>S2 – that would mean it would be easier to transport electricity. We wouldn't need as much electricity or energy.<br><br>ME – correct – now it means we need to generate more than we need for the work we want done because of the amount that is lost at heat. With a conductor that can conduct without resistance that would mean we would need to start with a smaller battery or we would not need to generate as much electricity at the source, eg coal-fired power stations, to do the work we want done.<br><br>Explanation of FLEET research<br><br>What else would that mean for how your laptop and phone would feel?<br><br>S1 – they wouldn't get hot.<br><br>ME – what comes into your head when you think of electricity now<br><br>S1 – I think of electron waves<br><br>S1 – electron waves, superconductors, different conductors<br><br>ME: what is it about different conductors? Eg, what did we learn about graphite. What about paper – was it a good conductor<br><br>S1/2 – no – (paper not a good conductor) | Understanding that having a conductor that could conduct without loss would reduce the amount of energy we need to use to do work, or that we wouldn't need as much electrical energy to do the same amount of work.<br><br>Understanding that there would be no generation of heat with a lossless conductor<br><br>Perceiving electrons as waves. Clarifying and reinforcing their understanding of electrons as waves.<br><br>Thinking about electrons as waves, superconductors and different conductors<br><br>Understanding that paper is a poor conductor<br>And that graphite is a an almost perfect conductor |

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| Graphite is a conductor, but not too good<br><br>S2– [re: resistance] I understand that force – that you need to apply more force to make sure that it will reach the destination<br><br>ME: If you apply more force to the circuit – eg a bigger battery, what does that mean for the atoms in the circuit? Or If I give you more energy, what happens to you<br><br>S1 – I will start to jiggle and come apart perhaps<br>And I feel heat<br><br>ME – Tell me more about what you understand about resistance<br><br>S1 – Electrons lose energy<br>ME: the more resistance there is…<br><br>S1 – The more energy they will lose<br><br>What would be the ideal circuit if we wanted to prevent energy loss<br><br>S1 – No resistance<br><br>ME - What comes into your head when you think of quantum physics – put into the Padlet | Understanding that with resistance you need to apply more force to make enough electrical energy for your needs<br><br>Understanding the by adding greater force (more energy into the circuit, the atoms will jiggle more (absorb kinetic energy) and give off more heat<br><br>Understanding that resistance is about electrons losing energy and that the more resistance there is the quicker electrons will lose their energy.<br><br>Perceiving the ideal circuit will have no resistance. |

Forces and Energy workshop

| Transcript | Analysis |
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| ME: What did you find with your pendulum<br><br>S1/S2 the more force we hit it (boxes) with the pendulum, the further they went.<br><br>ME: How did you get more force?<br><br>S1/S2 – More beanbags, or bringing it up further from 45 degrees to 90. | Learning that increasing the force, increased the effect<br><br>Understanding where the force was generated from in their pendulum (Increasing the force by adding mass or increasing the velocity of the beanbags) |

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| ME – If you have F=ma – what were you changing here | |
| S1/S2 The first time with bean bags we changed the mass and then we changed the angle to 90 degrees we changed the acceleration. | Understanding the relationship between force, mass and acceleration<br>Understanding how to increase the mass or acceleration to change the effect |
| ME - Tell me about energy now | Conceptualizing energy – see table below |
| S1/2 – kinetic and potential energy | |
| ME - What do we do with energy, how do we use it? What are we doing with our knowledge of kinetic and potential energy? | |
| S1/2 – make rockets, friction | |
| ME tell me about friction | |
| S1/2 – It (friction) increases the force you need to move an object<br>It creates heat as a byproduct | Understanding that the more friction there is, the greater the force needed to overcome it.<br>Understanding that friction creates heat |
| Devices – digital technologies | Linking devices/digi tech to energy |
| ME: How does energy help us make digital technologies? | |
| S1/2 Not sure | Understanding that digi tech uses electrical energy |
| ME – what sort of energy do they use? | |
| S1/2 – electrical energy | |
| ME: discussing graphene and our potential uses of graphene in circuits and to conduct a current, the problems we need to overcome to make this work. I mention nanowires | |
| S1/2 – I am not sure this would work because of quantum tunneling | Perceiving that nanowires would not work because of quantum tunneling<br>Being able to conceptualize quantum tunnelling as a quantum effect |
| ME: That is one of the complications they have to overcome. Which is why we are | |

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| trying to find new materials that will act as a semi-conductor but when they conduct they conduct without energy loss.<br><br>What else have we learned – what stood out<br><br>S1/2 – The pendulum experiment – as we haven't done that before | |
| ME Do this test. Pull the pendulum back out and put it against your chin, let it go and see if you can stay there without moving as the pendulum swings back<br>What do you think will happen?<br><br>S1/2 – I don't think it will hit me because there is friction and gravity stopping it…<br><br>ME: What did we learn with the pendulum<br><br>S1/2 – Not sure | Understanding how friction and gravity, as forces, affect the acceleration of the pendulum |
| ME: How can you use your knowledge to do something good in society.<br><br>S1/2 keep experimenting with graphene to make it stronger (I mentioned it was brittle)<br><br>We can experiment with other conductors that are as powerful as graphene, but where quantum tunneling does not happen. | Perceiving increasing energy efficiency of devices is a good thing<br>Describing the need to experiment with and improve the strength of graphene.<br>Believing we should experiment more with other conductors to make some that aren't affected by quantum tunneling |
| ME: maybe if we could stop this quantum tunneling then we could make things smaller, but then we rely on quantum tunneling for the sun – it is how the sun makes energy.<br><br>S1/2 In stead of stopping quantum tunneling what if we do research into something that uses quantum tunneling for the energy | Thinking outside the box. Suggesting we conduct research into finding ways to use the effect of quantum tunneling as an energy source. |

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| ME: yes, I mention that research groups are working on fusion energy. | |